Branching Ratios and Polarization in $B \to VV, VA, AA$ Decays

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Introduction

- We have studied B→ S (P,V), AP before. It is natural to generalize to AV,AA and revisit VV modes

  -- Generalization is highly nontrivial: $^3P_1$ & $^1P_1$ axial mesons which have very different decay constants & light cone distribution amplitudes

- Polarization puzzle in $\overline{B}$→VV decays

$$\overline{A}_0 : \overline{A}_- : \overline{A}_+ = 1 : \frac{\Lambda}{m_b} : \left(\frac{\Lambda}{m_b}\right)^2$$

In transversity basis $A_\perp = (A^- + A^+)/\sqrt{2}, \quad A_\parallel = (A^- - A^+)/\sqrt{2}$

$$f_T \equiv f_\parallel + f_\perp = 1 - f_L = O(m_V^2 / m_B^2), \qquad f_\parallel / f_\perp = 1 + O(m_V / m_B)$$

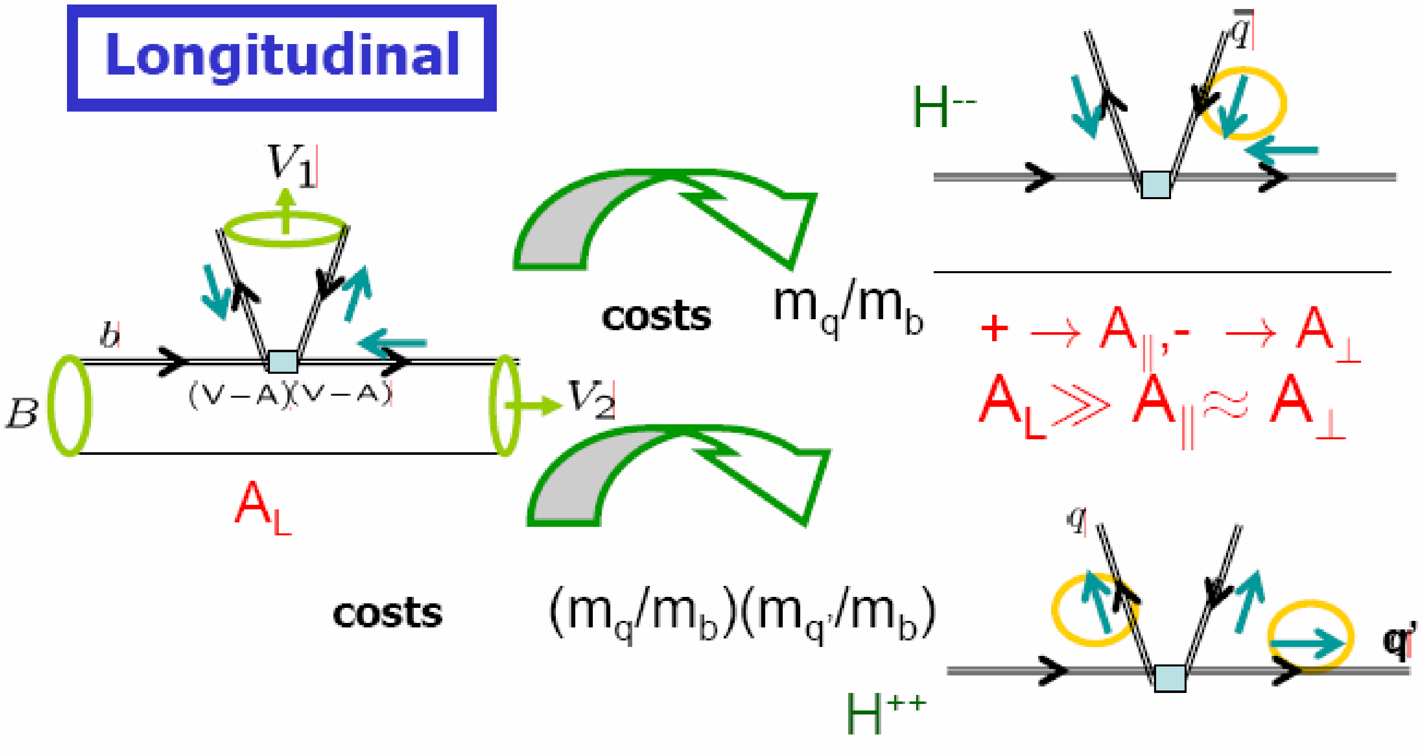
Why is f_T sizable ~ 0.5 in B→ $K^*\phi$ decays ?

$\bar{B}$ -> VV polarizations

left-handed (-)

right-handed (+)

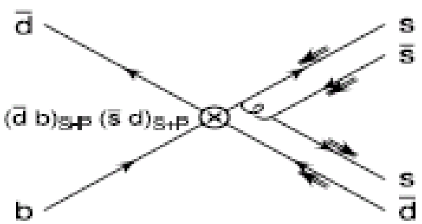
Transverse



The longitudinal component dominates

$$A^{00} >> A^{--} >> A^{++}$$

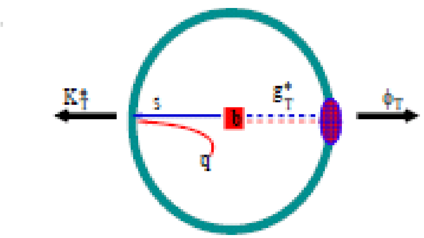
Polarization Anomaly: Some Ad hoc Models in SM



- **Annihilation diagram** (hep-ph/0405134) Kagan

  formally suppressed $1/m_b$

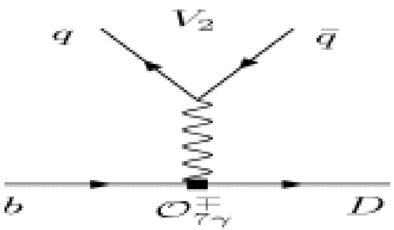
  not conclusive (vary free parameters)



- **Transverse gluon from $b \to sg$** (hep-ph/0408007) Hou, Nagashima

  analogy with γ from $B \to K^*\gamma$

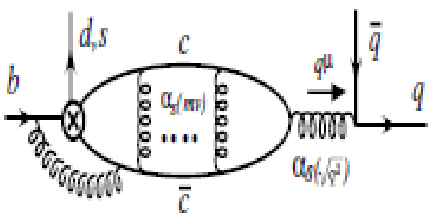
  seems to be suppressed, not conclusive



- **EM penguin** (hep-ph/0512258) Beneke, Rohrer, Yang

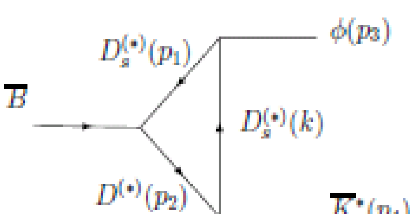
  similar polarization to $B \to K^*\gamma$

  appears only for neutral vector mesons



- **Charming penguins** (hep-ph/0401188) Bauer, Pirjol, Rothstein, Stewart

  rely on free parameters, not conclusive



- **Long-distance rescattering** (hep-ph/0409317) HYC,Chua,Soni; Colangelo, De Farzio; Pham

  model-dependent, constrained by other data

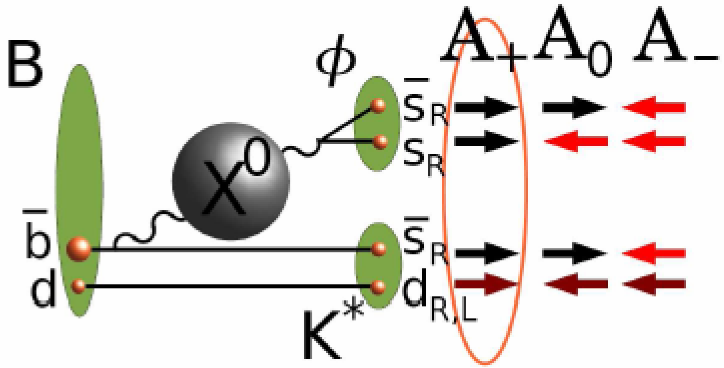
  expect $f_L \sim f_{\parallel} \gg f_{\perp}$ (?)

Possible New Physics in Polarization

violate $|A_0|^2 \gg |A_+|^2 \gg |A_-|^2$

$\bar{q}\gamma^\mu(1-\gamma^5)q$

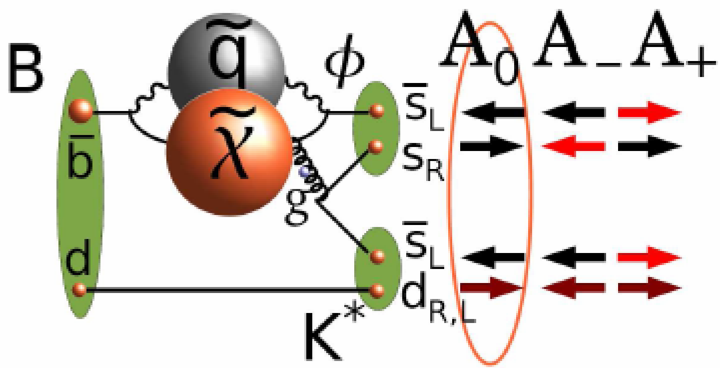
scalar interaction



$|A_+|^2 \gg |A_0|^2 \gg |A_-|^2$

$\bar{q}(1+\gamma^5)q$

supersymmetry

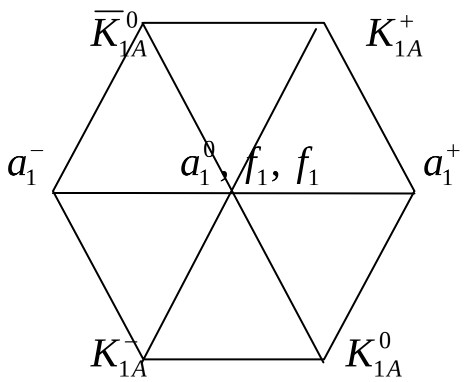


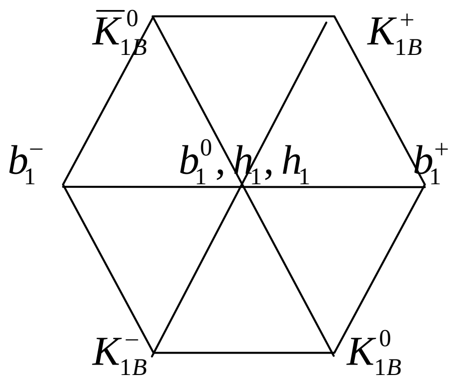
$|A_0|^2 \gg |A_-|^2 \gg |A_+|^2$

$\bar{q}\gamma^\mu(1+\gamma^5)q$

Axial-vector mesons

$^3P_1$ (1^{++})





$^1P_1$ (1^{+-})

For $J^P=1^+$ axial-vector mesons, two nonets have been observed:

- **$^3P_1$ nonet (S=1)**

  I=0: $f_1(1285)$, $f_1(1420)$, I=1/2: K_{1A}, I=1: $a_1(1260)$,

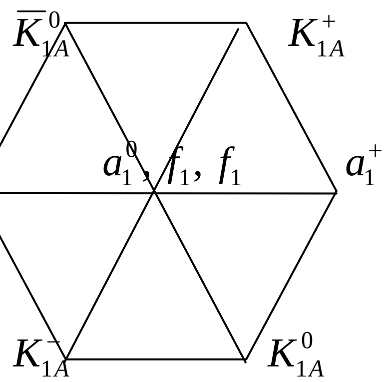
- **$^1P_1$ nonet (S=0)**

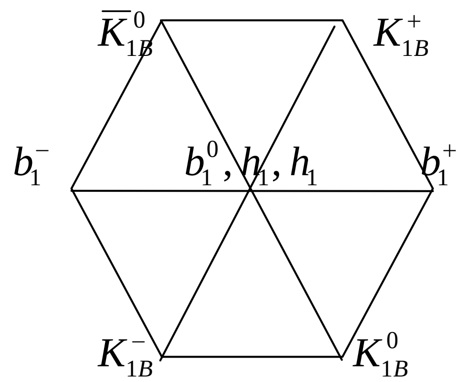
  I=0: $h_1(1170)$, $h_1(1380)$, I=1/2: K_{1B} , I=1: $b_1(1235)$

K_{1A}, $K_{1B} \rightarrow K_1(1270)$, $K_1(1400)$

Mixing angles

$^3P_1$ (1^{++})





$^1P_1$ (1^{+-})

- $^3P_1$ states $f_1(1285)$ & $f_1(1420)$ have mixing [so are $^1P_1$ states $h_1(1170)$ & $h_1(1380)$]

$$|f_1(1285)\rangle = |f_1\rangle \cos\theta_{^3P_1} + |f_8\rangle \sin\theta_{^3P_1}, \quad |f_1(1420)\rangle = -|f_1\rangle \sin\theta_{^3P_1} + |f_8\rangle \cos\theta_{^3P_1}.$$

$$\cos^2\theta_{^3P_1} = \frac{4m^2_{K_{1A}} - m^2_{a_1} - 3m^2_{f_1(1285)}}{3\left(m^2_{f_1(1420)} - m^2_{f_1(1285)}\right)},$$

magnitude of θ

$$\tan\theta_{^3P_1} = \frac{4m^2_{K_{1A}} - m^2_{a_1} - 3m^2_{f_1(1420)}}{2\sqrt{2}(m^2_{a_1} - m^2_{K_{1A}})}.$$

sign of θ

θ_{3P1} & θ_{1P1} depend on the K_{1A}-K_{1B} mixing angle

- No a_1 and b_1 mixing due to opposite C or G parities

■ In SU(3) limit, K_{1A} & K_{1B} do not get mixed. However, they have admixture due to strange and light quark mass difference

$$K_1(1270) = K_{1A}\sin\theta_K + K_{1B}\cos\theta_K \qquad \overline{K}_1(1270) = -K_{1A}\sin\theta_K + K_{1B}\cos\theta_K$$
$$K_1(1400) = K_{1A}\cos\theta_K - K_{1B}\sin\theta_K \qquad \overline{K}_1(1400) = K_{1A}\cos\theta_K + K_{1B}\sin\theta_K$$

■ PDG ⇒ $|\theta_K| \approx 45^o$

■ Strong decays $K_1(1270)$, $K_1(1400) \to K\rho, K^*\pi$ and their masses ⇒ $\theta_K = \pm 32^\circ, \pm 56^\circ$ (Suzuki,'93)

$\tau \to K_1(1270)\nu_\tau, K_1(1400)\nu_\tau \Rightarrow \theta_K = \pm 37^\circ, \pm 58^\circ$ (HYC,'03)

Sign of θ_K depends on the phase convention of states. It can be inferred from $B \to K_1\gamma$ decays (HYC,Chua, '05; Yang, Hatanaka, '08)

$$\frac{\mathcal{B}(B\to K_1(1270)\gamma)}{\mathcal{B}(B\to K_1(1400)\gamma)} = \begin{cases} 10.1\pm 6.2 \ \ (280\pm 200); & \text{for } \theta_{K_1} = -58^\circ \ (-37^\circ), \\ 0.02\pm 0.02 \ (0.05\pm 0.04); & \text{for } \theta_{K_1} = +58^\circ \ (+37^\circ). \end{cases}$$

$$Br(B^+ \to K_1^+(1270)\gamma) = (4.3 \pm 0.9 \pm 0.9)\times 10^{-5}$$
$$Br(B^+ \to K_1^+(1400)\gamma) < 1.5\times 10^{-5}$$

Belle measurement favors a negative θ

Decay constants

$$\langle A(p,\varepsilon)|\bar{q}\gamma_\mu\gamma_5 q'|0\rangle = i f_A m_A \varepsilon^*_\mu, \qquad \langle A(p,\varepsilon)|\bar{q}\sigma_{\mu\nu}\gamma_5 q'|0\rangle = -f_A^\perp(\varepsilon^*_\mu p_\nu - \varepsilon^*_\nu p_\mu)$$

scale dependent

- Decay constant of b_1° vanishes due to $C[b_1]= -$ and $CA_\mu C^{-1}=A_\mu$
- Decay constant of charged $b_1^\pm$ vanishes in isospin limit due to $G[b_1]=+$ & $GA_\mu G^{-1}=-A_\mu$. We obtain $f[b_1^+]=0.6\pm0.2$ MeV, $f[b_1^-]= - 0.6\pm0.2$ MeV
- In SU(3) limit

$$M_a^b(^3P_1) \to M_b^a(^3P_1), \qquad M_a^b(^1P_1) \to -M_b^a(^1P_1), \quad (a,b=1,2,3).$$

Since $(A_\mu)_a{}^b \to (A_\mu)_b{}^a$ under charge conjugation $\Rightarrow$ $f[^1P_1]=0$ in SU(3) limit

By the same token, $f^\perp[^3P_1]=0$ in the same limit

$^3P_1$	$a_1(1260)$	f_1	f_8	K_{1A}
$f_{^3P_1}$	238 ± 10	245 ± 13	239 ± 13	250 ± 13

$^1P_1$	$b_1(1235)$	h_1	h_8	K_{1B}
$f^\perp_{^1P_1}$	180 ± 8	180 ± 12	190 ± 10	190 ± 10

QCDSR by K.C. Yang

Form factors for $B \to A$

- **ISGW (Isgur-Scora-Grinstein-Wise) non-relativistic quark model ('89,'95)**
- **Covariant light-front quark model (Chua,Hwang, HYC, '04)**

  Relativistic effects in B-to-light transitions at $q^2=0$ are important
- **Light cone sum rules (K.C. Yang, '07,'08)**
- **pQCD approach (W. Wang, R.H. Li, C.D. Lu, hep-ph/0711.0432)**

	ISGW2	CQM	CLF	LQSR	pQCD	expt
$V_0^{Ba_1}(0)$	1.01	1.20	0.13	0.30	0.34	~ 0.31

$B \to a_1$ form factors predicted by ISGW2 & CQM models are too large !

ISGW2, QCDSR: f $[^1P_1]$, f $[^3P_1]$ of the same sign

$B \to {}^1P_1$ and $B \to {}^3P_1$ form factors are opposite in sign

θ_K is negative

CLFQM, pQCD: f $[^1P_1]$, f $[^3P_1]$ have opposite signs

$B \to {}^1P_1$ and $B \to {}^3P_1$ form factors of same sign

θ_K is positive

Light-cone distribution amplitudes (LCDAs)

chiral-even

$$\langle A(P,\lambda)|\bar{q}_1(y)\gamma_\mu\gamma_5 q_2(x)|0\rangle = i m_A \int_0^1 du\, e^{i(u\, py+\bar{u}\, px)} \left\{ p_\mu \frac{\epsilon^{(\lambda)*} z}{pz} \Phi_{\parallel}(u) + \epsilon^{(\lambda)*}_{\perp\mu} g_\perp^{(a)}(u) \right\}$$

$$\langle A(P,\lambda)|\bar{q}_1(y)\gamma_\mu q_2(x)|0\rangle = -i m_A\, \epsilon_{\mu\nu\rho\sigma}\, \epsilon^{*\nu}_{(\lambda)} p^\rho z^\sigma \int_0^1 du\, e^{i(u\, py+\bar{u}\, px)} \frac{g_\perp^{(v)}(u)}{4}$$

chiral-odd

$$\langle A(P,\lambda)|\bar{q}_1(y)\sigma_{\mu\nu}\gamma_5 q_2(x)|0\rangle = \int_0^1 du\, e^{i(u\, py+\bar{u}\, px)} \left\{ (\epsilon^{(\lambda)*}_{\perp\mu} p_\nu - \epsilon^{(\lambda)*}_{\perp\nu} p_\mu) \Phi_\perp(u) + \frac{m_A^2\, \epsilon^{(\lambda)*} z}{(pz)^2} (p_\mu z_\nu - p_\nu z_\mu) h_{\parallel}^{(t)}(u) \right\},$$

$$\langle A(P,\lambda)|\bar{q}_1(y)\gamma_5 q_2(x)|0\rangle = m_A^2 \epsilon^{(\lambda)*} z \int_0^1 du\, e^{i(u\, py+\bar{u}\, px)} \frac{h_{\parallel}^{(p)}(u)}{2}.$$

twist-2: $\Phi_{\parallel}, \Phi_\perp$

twist-3: $g_\perp^{(v)}, g_\perp^{(a)}, h_\perp^{(t)}, h_{\parallel}^{(p)}$ related to twist-2 ones via Wandzura-Wilczek relations (neglecting 3-parton distributions)

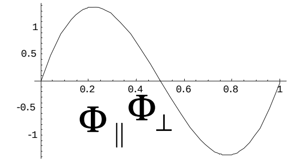
$$\Phi_{\parallel}^A(u) = 6u\bar{u}\, f_A \left[a_0^{\parallel,A} + \sum_{i=1}^{\infty} a_i^{\parallel,A} C_i^{3/2}(2u-1) \right]$$

$C_i^{3/2}$: Gegenbauer polynomial

Since $f[b_1^o]=0$, how to construct LCDA $\Phi_{\parallel}$ for neutral b_1 ?

$^1P_1$ meson

Due to even G-parity, $\Phi_\perp$, $h_\parallel^{(t)}$, $h_\parallel^{(p)}$ are symmetric under u→1-u, while $\Phi_\parallel$, $g_\perp^{(v)}$, $g_\perp^{(a)}$ are antisymmetric with the replacement u→1-u in SU(3) limit



$$\Phi_\perp^{^1P_1}(u) = f_{^1P_1}^\perp 6u\bar{u}\left\{1 + 3a_1^{\perp,^1P_1}(2u-1) + a_2^{\perp,^1P_1}\frac{3}{2}\left[5(2u-1)^2 - 1\right]\right\} \qquad \int_0^1 du\Phi_\perp^{^1P_1}(u) = f_{^1P_1}^\perp$$

(1) $$\Phi_\parallel^{^1P_1}(u) = f_{^1P_1}^\perp 6u\bar{u}\left\{a_0^{\parallel,^1P_1} + 3a_1^{\parallel,^1P_1}(2u-1) + a_2^{\parallel,^1P_1}\frac{3}{2}\left[5(2u-1)^2 - 1\right]\right\}$$

$$\int_0^1 du\Phi_\parallel^{^1P_1}(u) = f_{^1P_1} \qquad \Rightarrow \qquad \boxed{f_{^1P_1} = f_{^1P_1}^\perp(\mu)a_0^{\parallel,^1P_1}(\mu)}$$

LCDA $\Phi_\parallel^{^1P_1}$ can be recast to the form

(2) $$\Phi_\parallel^{^1P_1}(u) = f_{^1P_1} 6u\bar{u}\left\{1 + \mu_{^1P_1}\sum_{i=1}^{2} a_i^{\parallel,^1P_1} C_i^{3/2}(2u-1)\right\}$$ with $$\mu_{^1P_1} = 1/a_0^{\parallel,^1P_1}.$$

- For neutral b_1, $f_{b1}=0$, but $f_{b1}\mu_{b1}=f_{b1}^\perp$ is finite !
- This is very similar to the scalar meson case where f [f_0, a_0^0, σ]=0, but decay constant defined by <S|$\underline{q}_1 q_2$|0>=$m_S \bar{f}_S$ is not vanishing. LCDA (1) and (2) are equivalent for describing $\Phi_\parallel$ for $^1P_1$ meson

$^3P_1$ meson

Due to odd G-parity, $\Phi_\perp$, $h_\parallel^{(t)}$, $h_\parallel^{(p)}$ are anti-symmetric under u→1-u, while $\Phi_\parallel$, $g_\perp^{(v)}$, $g_\perp^{(a)}$ are symmetric with the replacement u→1-u in SU(3) limit

(1)

$$\Phi_\parallel^{^3P_1}(u) = f_{^3P_1} 6u\bar{u}\left\{1 + 3a_1^{\parallel,^3P_1}(2u-1) + a_2^{\parallel,^3P_1}\frac{3}{2}\left[5(2u-1)^2 - 1\right]\right\},$$

$$\Phi_\perp^{^3P_1}(u) = f_{^3P_1} 6u\bar{u}\left\{a_0^{\perp,^3P_1} + 3a_1^{\perp,^3P_1}(2u-1) + a_2^{\perp,^3P_1}\frac{3}{2}\left[5(2u-1)^2 - 1\right]\right\}$$

$$\int_0^1 du\Phi_\parallel^{^3P_1}(u) = f_{^3P_1}, \qquad \int_0^1 du\Phi_\perp^{^3P_1}(u) = f_{^3P_1}^\perp \quad \Rightarrow \quad f_{^3P_1}^\perp(\mu) = f_{^3P_1} a_0^{\perp,^3P_1}(\mu).$$

LCDA $\Phi_\perp^{^3P_1}$ can be recast to the form

(2)

$$\Phi_\perp^{^3P_1}(u) = f_{^3P_1}^\perp 6u\bar{u}\left\{1 + \mu_{^3P_1}\sum_{i=1}^{2} a_i^{\perp,^3P_1} C_i^{3/2}(2u-1)\right\}$$

with $\mu_{^3P_1} = 1/a_0^{\perp,^3P_1}$

One can use LCDA (1) or (2) to describe $\Phi_\perp$ for $^3P_1$ meson

Gegenbauer moments

K.C. Yang, Nucl. Phys. B776, 187 (2007)

μ	$a_2^{\parallel,a_1(1260)}$	$a_2^{\parallel,f_1^{^3P_1}}$	$a_2^{\parallel,f_8^{^3P_1}}$	$a_2^{\parallel,K_{1A}}$	$a_1^{\parallel,K_{1A}}$
1 GeV	-0.02 ± 0.02	-0.04 ± 0.03	-0.07 ± 0.04	-0.05 ± 0.03	$-0.30^{+0.26}_{-0.00}$
2.2 GeV	-0.01 ± 0.01	-0.03 ± 0.02	-0.05 ± 0.03	-0.04 ± 0.02	$-0.24^{+0.21}_{-0.00}$

μ	$a_1^{\perp,a_1(1260)}$	$a_1^{\perp,f_1^{^3P_1}}$	$a_1^{\perp,f_8^{^3P_1}}$	$a_1^{\perp,K_{1A}}$	$a_0^{\perp,K_{1A}}$	$a_2^{\perp,K_{1A}}$
1 GeV	-1.04 ± 0.34	-1.06 ± 0.36	-1.11 ± 0.31	-1.08 ± 0.48	$0.26^{+0.03}_{-0.22}$	0.02 ± 0.21
2.2 GeV	-0.81 ± 0.26	-0.82 ± 0.28	-0.86 ± 0.24	-0.84 ± 0.37	$0.24^{+0.03}_{-0.21}$	0.01 ± 0.15

μ	$a_1^{\parallel,b_1(1235)}$	$a_1^{\parallel,h_1^{^1P_1}}$	$a_1^{\parallel,h_8^{^1P_1}}$	$a_1^{\parallel,K_{1B}}$	$a_0^{\parallel,K_{1B}}$	$a_2^{\parallel,K_{1B}}$
1 GeV	-1.95 ± 0.35	-2.00 ± 0.35	-1.95 ± 0.35	-1.95 ± 0.45	-0.15 ± 0.15	$0.09^{+0.16}_{-0.18}$
2.2 GeV	-1.56 ± 0.28	-1.60 ± 0.28	-1.56 ± 0.28	-1.56 ± 0.36	-0.15 ± 0.15	$0.06^{+0.11}_{-0.13}$

μ	$a_2^{\perp,b_1(1235)}$	$a_2^{\perp,h_1^{^1P_1}}$	$a_2^{\perp,h_8^{^1P_1}}$	$a_2^{\perp,K_{1B}}$	$a_1^{\perp,K_{1B}}$
1 GeV	0.03 ± 0.19	0.18 ± 0.22	0.14 ± 0.22	-0.02 ± 0.22	$0.30^{+0.00}_{-0.31}$
2.2 GeV	0.02 ± 0.14	0.14 ± 0.17	0.11 ± 0.17	-0.02 ± 0.17	$0.25^{+0.00}_{-0.26}$

B→ VV in QCDF

HYC, K.C. Yang, 2001

Li, Lu, Y.D. Yang, 2003, 2005

Kagan, 2004 (penguin annihilation)

Zou, Xiao, 2005

Y.D. Yang, Wang, Lu, 2005

Das, K.C. Yang, 2005

Huang, Ko, Wu, Y.D. Yang, 2006

Beneke, Rohrer, D.S. Yang, 2007

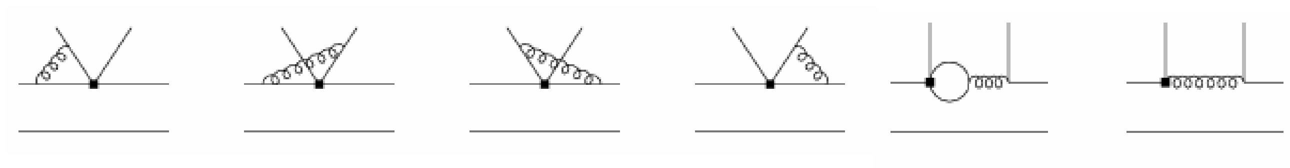
Most of early results do not agree with each other due mainly to incorrect projection on polarization states (except Das & Yang); all have errors (except Kagan) and none complete.

Beneke et al. obtained complete NLO corrections to a_i^h & computed LO weak annihilation.

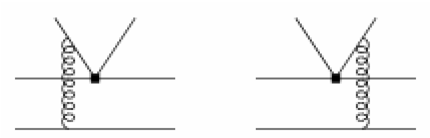
B→ VV,VA,AA in QCDF

Apply QCD factorization to B→VV,VA,AA (Beneke, Buchalla, Neubert, Sachrajda)

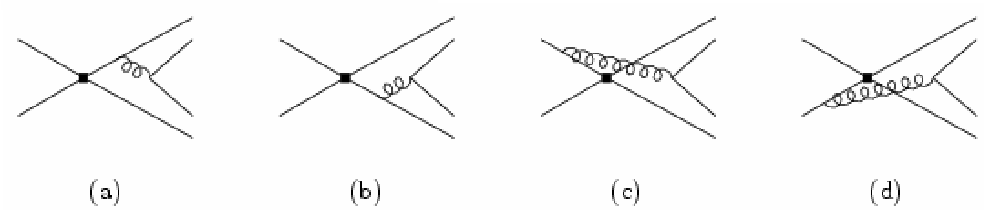
vertex & penguin



hard spectator int.



annihilation



$$a_i^{p,h}(M_1M_2) = \left(c_i + \frac{c_{i\pm1}}{N_c}\right) N_i^h(M_2) + \frac{c_{i\pm1}}{N_c}\frac{C_F\alpha_s}{4\pi}\left[V_i^h(M_2) + \frac{4\pi^2}{N_c}H_i^h(M_1M_2)\right] + P_i^{h,p}(M_2),$$

$$N_i(M_2) = \begin{cases} 0, & i = 6, 8, \\ 1, & \text{else.} \end{cases}$$

$$= \begin{cases} 1 & \text{for } {}^3P_1 \\ a_0^{\parallel, {}^1P_1} & \text{for } {}^1P_1\text{, vanishes in SU(3) limit} \end{cases}$$

$$M_\parallel^V = -i\frac{f_V}{4}\frac{m_V(\epsilon^*_{(\lambda)}n_+)}{2}\not{n}_-\,\Phi_\parallel(u) - i\frac{f_V^\perp m_V}{4}\frac{m_V(\epsilon^*_{(\lambda)}n_+)}{2E}\Big\{-\frac{i}{2}\sigma_{\mu\nu}\,n_-^\mu n_+^\nu\,h_\parallel^{(t)}(u)$$

$$-iE\int_0^u dv\,(\Phi_\perp(v) - h_\parallel^{(t)}(v))\,\sigma_{\mu\nu}n_-^\mu\,\frac{\partial}{\partial k_{\perp\nu}} + \frac{h_\parallel'^{(s)}(u)}{2}\Big\}\Big|_{k=up} + \mathcal{O}\Big[\Big(\frac{m_V}{E}\Big)^2\Big],$$

$$M_\perp^V = -i\frac{f_V^\perp}{4}E\,\not{\epsilon}_\perp^{*(\lambda)}\,\not{n}_-\,\Phi_\perp(u)$$

$$-i\frac{f_V m_V}{4}\Big\{\not{\epsilon}_\perp^{*(\lambda)}\,g_\perp^{(v)}(u) - E\int_0^u dv\,(\Phi_\parallel(v) - g_\perp^{(v)}(v))\,\not{n}_-\,\epsilon_{\perp\mu}^{*(\lambda)}\,\frac{\partial}{\partial k_{\perp\mu}}$$

$$+i\varepsilon_{\mu\nu\rho\sigma}\,\gamma^\mu\epsilon_\perp^{*(\lambda)\nu}\,n_-^\rho\gamma_5\Big[n_+^\sigma\frac{g_\perp'^{(a)}(u)}{8} - E\frac{g_\perp^{(a)}(u)}{4}\frac{\partial}{\partial k_{\perp\sigma}}\Big]\Big\}\Big|_{k=up} + \mathcal{O}\Big[\Big(\frac{m_V}{E}\Big)^2\Big],$$

$$M_\parallel^A = -i\frac{f_A}{4}\frac{m_A(\epsilon^*_{(\lambda)}n_+)}{2}\not{n}_-\gamma_5\,\Phi_\parallel(u) + i\frac{f_A^\perp m_A}{4}\frac{m_A(\epsilon^*_{(\lambda)}n_+)}{2E}\Big\{-\frac{i}{2}\sigma_{\mu\nu}\gamma_5\,n_-^\mu n_+^\nu\,h_\parallel^{(t)}(u)$$

$$-iE\int_0^u dv\,(\Phi_\perp(v) - h_\parallel^{(t)}(v))\,\sigma_{\mu\nu}\gamma_5 n_-^\mu\,\frac{\partial}{\partial k_{\perp\nu}} + \gamma_5\frac{h_\parallel'^{(p)}(u)}{2}\Big\}\Big|_{k=up} + \mathcal{O}\Big[\Big(\frac{m_A}{E}\Big)^2\Big]$$

$$M_\perp^A = i\frac{f_A^\perp}{4}E\,\not{\epsilon}_\perp^{*(\lambda)}\,\not{n}_-\gamma_5\,\Phi_\perp(u)$$

$$-i\frac{f_A m_A}{4}\Big\{\not{\epsilon}_\perp^{*(\lambda)}\gamma_5\,g_\perp^{(a)}(u) - E\int_0^u dv\,(\Phi_\parallel(v) - g_\perp^{(a)}(v))\,\not{n}_-\gamma_5\,\epsilon_{\perp\mu}^{*(\lambda)}\,\frac{\partial}{\partial k_{\perp\mu}}$$

$$+i\varepsilon_{\mu\nu\rho\sigma}\,\gamma^\mu\epsilon_\perp^{*(\lambda)\nu}\,n_-^\rho\Big[n_+^\sigma\frac{g_\perp'^{(v)}(u)}{8} - E\frac{g_\perp^{(v)}(u)}{4}\frac{\partial}{\partial k_{\perp\sigma}}\Big]\Big\}\Big|_{k=up} + \mathcal{O}\Big[\Big(\frac{m_A}{E}\Big)^2\Big]$$

Transverse momentum derivative terms should be included before taking collinear approximation

■ Factorization breaks down for transverse polarization amplitudes even at leading power [HYC, Yang,…; Beneke et al.]

Hard spectator scattering:

$H^-_{1,5}$ have log div., H^+_1 has log and linear div

$$\int_0^1 \frac{dx}{x} \equiv X \rightarrow \ln\left(\frac{m_B}{\Lambda_h}\right)(1+\rho\, e^{i\phi})$$

■ Nonfactorization ⇒ transverse polarization amplitudes are on much less solid footing than longitudinal ones

$B \to K^* \phi$

$$\mathcal{A}^h_{\bar{B}\to\bar{K}^*\phi} \approx V_c(\alpha_3^h + \alpha_4^{c,h} + \beta_3^h - \frac{1}{2}\alpha^h_{3,\rm EW})X^h_{\bar{K}^*\phi}.$$

α_3=a_3+a_5, α_4=a_4-$r_\chi^{\phi}a_6$, $\alpha_{3,EW}$=a_9+a_7, β_3= penguin ann

$$X^h_{\bar{K}^*\phi} = \langle \phi | J_\mu | 0 \rangle \langle \overline{K}^* | J^\mu | B \rangle, \qquad | X^0_{\bar{K}^*\phi} | : | X^-_{\bar{K}^*\phi} | : | X^+_{\bar{K}^*\phi} | = 1 : 0.35 : 0.007$$

	h=0	h= -		h=0	h= -
$\alpha_3(K^*\phi)$	$0.005 - 0.001i$	$-0.004 - 0.001i$	$\alpha_{3,\rm EW}(K^*\phi)$	$-0.009 - 0.000i$	$0.002 - 0.000i$
$\alpha_4^u(K^*\phi)$	$-0.022 - 0.014i$	$-0.047 - 0.016i$	$\alpha_4^c(K^*\phi)$	$-0.027 - 0.014i$	$-0.049 - 0.006i$

Coefficients are helicity dependent !

$$\left.\frac{\mathcal{A}^-}{\mathcal{A}^0}\right|_{\bar{B}\to\bar{K}^*\phi} \approx \left(\frac{\alpha_3^- + \alpha_4^{c,-} - \frac{1}{2}\alpha^-_{3,\rm EW}}{\alpha_3^0 + \alpha_4^{c,0} - \frac{1}{2}\alpha^0_{3,\rm EW}}\right)\left(\frac{X^-_{\bar{K}^*\phi}}{X^0_{\bar{K}^*\phi}}\right)$$ with β_3=0

constructive (destructive) interference in A^- (A^0) $\Rightarrow$ $f_L \approx 0.58$

Any serious model for solving polarization enigma should consider NLO corrections

Although f_L is reduced to 60% level, polarization puzzle is not resolved as the predicted rate, BR$\sim$ 4.3$\times 10^{-6}$, is too small compared to the data, $\sim$ 10$\times 10^{-6}$ for B $\rightarrow K^*\phi$

$$P^c = [a_4^c + r_\chi a_6^c]_{SD} + \underbrace{[a_4^c + r_\chi a_6^c]_{LD}}_{\text{charming penguin, FSI}} + \underbrace{\beta_3^c}_{\text{penguin annihilation}} + \ldots$$

- Br & f_L are fit by adjusting $X_A = \ln\left(\frac{m_B}{\Lambda_h}\right)(1+\rho_A e^{i\phi_A})$ Kagan ('04)

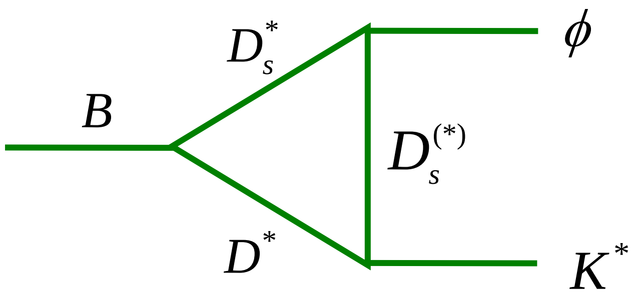
$\Rightarrow$ ρ_A=0.60, ϕ_A=-50°

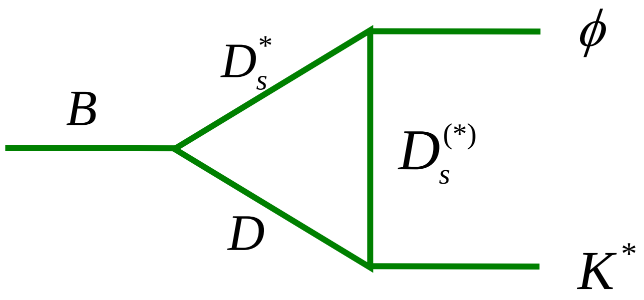
Decay	$\mathcal{B}$		f_L		$f_\perp$	
	Theory	Expt	Theory	Expt	Theory	Expt
$B^- \to K^{*-}\phi$ [c]	$10.0^{+1.3+14.1}_{-1.1-\ 6.3}$	10.0 ± 1.1	$0.49^{+0.51}_{-0.38}$	0.50 ± 0.05	$0.25^{+0.20}_{-0.25}$	0.20 ± 0.05
$\overline{B}^0 \to \bar{K}^{*0}\phi$	$9.5^{+1.2+13.5}_{-1.1-\ 6.1}$	9.5 ± 0.8	$0.50^{+0.50}_{-0.38}$	0.484 ± 0.034	$0.25^{+0.19}_{-0.25}$	0.256 ± 0.032

$f_{||} \approx f_\perp \sim 0.25$

We use ρ_A & ϕ_A to *accommodate* the data of Br & f_L rather than to *predict* them

■ Get large transverse polarization from $B \to D_s^* D^*$ and then convey it to ϕK^* via FSI (or charming penguin) [HYC, Chua, Soni; Colangelo, De Farzio, Pham]



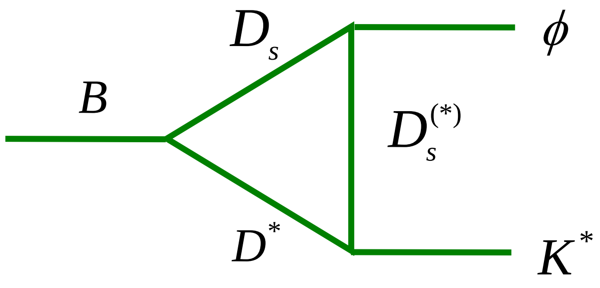


$f_L(D_s^* D^*) \sim 0.51$

$f_{||} \sim 0.41$, $f_\perp \sim 0.08$

contributes to $f_\perp$ only

Large cancellation occurs in $B \to \{D_s^* D, D_s D^*\} \to \phi K^*$ processes. This can be understood as CP & SU(3) symmetry



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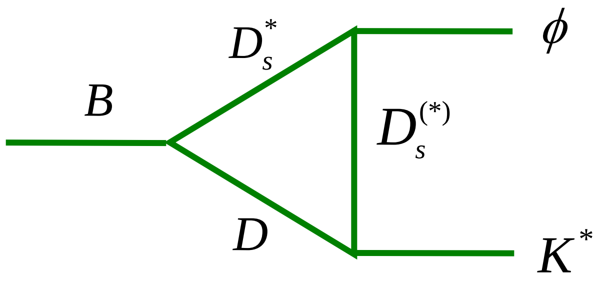


≈ 0 !

⇒ very small perpendicular polarization, $f_\perp \sim 2\%$, in sharp contrast to $f_\perp \sim 15\%$ obtained by Colangelo et al.

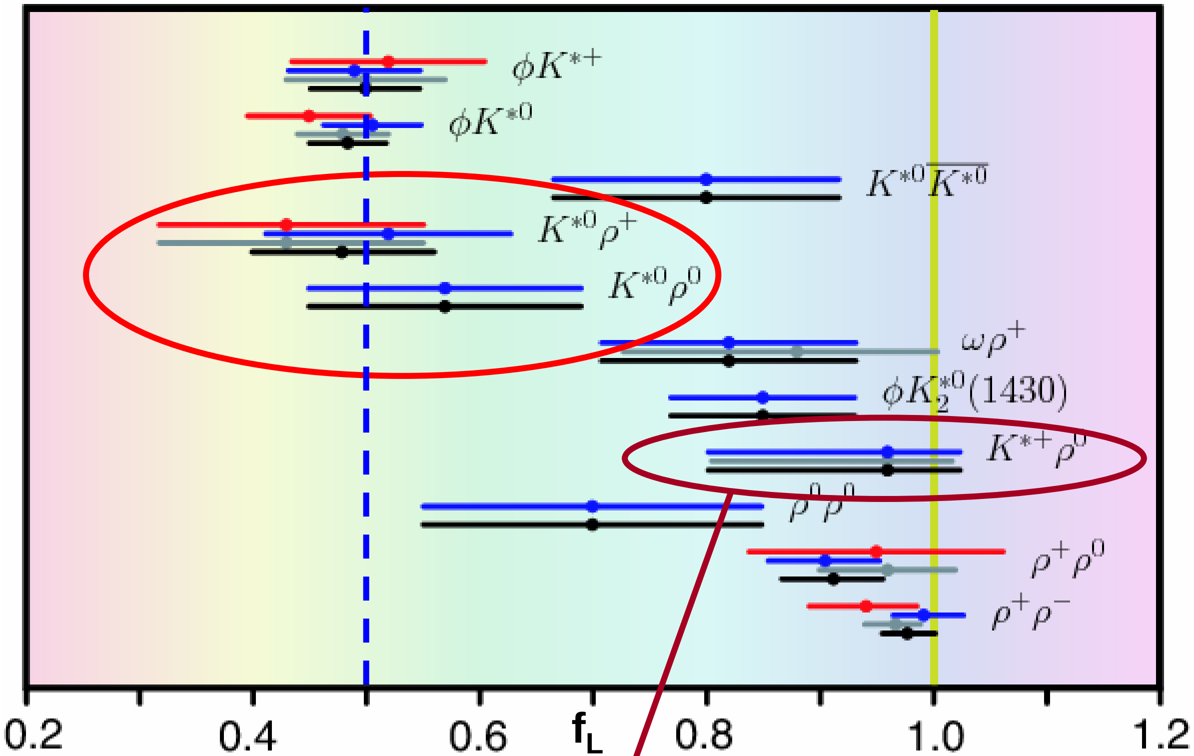
While $f_T \approx 0.50$ is achieved, why is $f_\perp$ not so small ?

◆ Cancellation in $B \to \{VP, PV\} \to \phi K^*$ can be circumvented in $B \to \{SA, AS\} \to \phi K^*$. For $S, A = D^{**}, D_s^{**}$ $\Rightarrow$ $f_\perp \sim 0.22$

◆ It is easy to explain the rate deficit & $f_L \approx 0.50$ via FSI, but it takes some efforts to accommodate $f_\perp \sim f_{||}$

◆ Ways of distinguishing penguin annihilation from recattering have been proposed by London et al. [arXiv:0802.0897]

$B \to K^* \rho$



Decay	Expt	
	$\mathcal{B}$	f_L
$B^- \to \bar{K}^{*0}\rho^-$	9.2 ± 1.5	0.48 ± 0.08
$B^- \to K^{*-}\rho^0$	< 6.1	$0.96^{+0.06}_{-0.16}$
$\overline{B}^0 \to K^{*-}\rho^+$	< 12	$-$
$\overline{B}^0 \to \bar{K}^{*0}\rho^0$	5.6 ± 1.6	0.57 ± 0.12

While $f_L(K^{*0}\rho^-, K^{*0}\rho\} \sim$ ½, $K^{*-}\rho^0$ is dominated by longitudinal polarization

even more puzzling !

Parameter	$h=0$	$h=-$	Parameter	$h=0$	$h=-$
$\alpha_1(\rho K^*)$	$0.96+0.02i$	$1.11+0.03i$	$\alpha_{3,\rm EW}(K^*\rho)$	$-0.009-0.000i$	$0.005-0.000i$
$\alpha_2(K^*\rho)$	$0.28-0.08i$	$-0.17-0.17i$	$\alpha_{4,\rm EW}(K^*\rho)$	$-0.002+0.001i$	$0.001+0.001i$
$\alpha_4^u(\rho K^*)$	$-0.022-0.014i$	$-0.048-0.016i$	$\beta_3(\rho K^*)$	$0.015-0.020i$	$-0.012+0.016i$
$\alpha_4^c(\rho K^*)$	$-0.026-0.014i$	$-0.050-0.006i$			

$$\frac{\mathcal{A}^-}{\mathcal{A}^0}\bigg|_{\bar B^0\to\bar K^{*0}\rho^0} \approx \left(\frac{\alpha_4^{c,-}-\frac{3}{2}\alpha_{3,\rm EW}^-}{\alpha_4^{c,0}-\frac{3}{2}\alpha_{3,\rm EW}^0}\right)\left(\frac{X^-_{\bar K^*\rho}}{X^0_{\bar K^*\rho}}\right)$$

constructive / destructive

$$\frac{\mathcal{A}^-}{\mathcal{A}^0}\bigg|_{B^-\to K^{*-}\rho^0} \approx \left(\frac{\alpha_4^{c,-}+\frac{3}{2}\alpha_{3,\rm EW}^-}{\alpha_4^{c,0}+\frac{3}{2}\alpha_{3,\rm EW}^0}\right)\left(\frac{X^-_{\bar K^*\rho}}{X^0_{\bar K^*\rho}}\right)$$

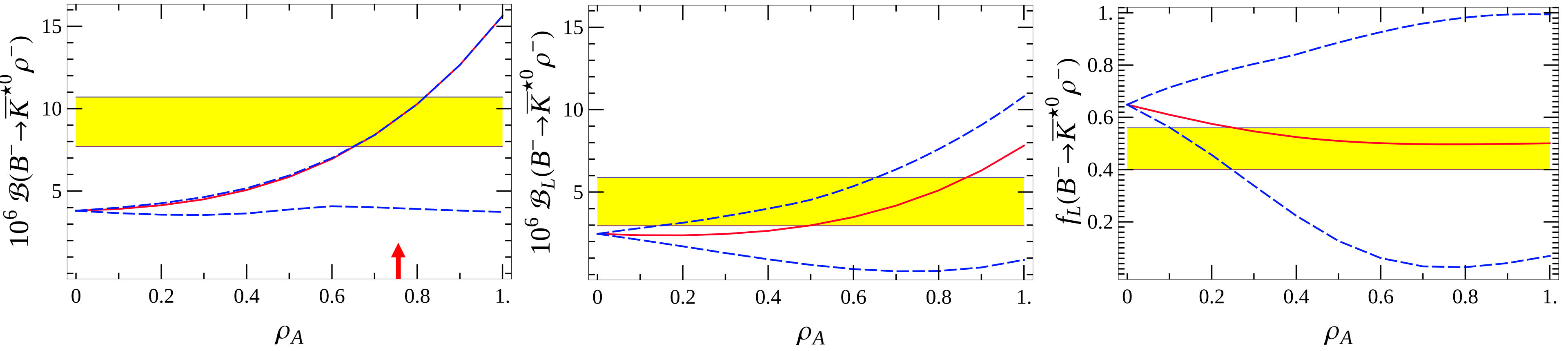
destructive / constructive

with $\beta_3=0$

⇒ $f_L(K^{*-}\rho^0)=0.96$, $f_L(K^{*0}\rho^0)=0.47$ (=0.91 if a_i^h are helicity indep)

Decay	Expt		(i)	
	$\mathcal{B}$	f_L	$\mathcal{B}$	f_L
$B^-\to\bar K^{*0}\rho^-$	9.2 ± 1.5	0.48 ± 0.08	3.8	0.78
$B^-\to K^{*-}\rho^0$	<6.1	$0.96^{+0.06}_{-0.16}$	3.6	0.96
$\overline{B}^0\to K^{*-}\rho^+$	<12	–	3.6	0.84
$\overline{B}^0\to\bar K^{*0}\rho^0$	5.6 ± 1.6	0.57 ± 0.12	1.1	0.47

But, the predicted rates for $K^{*-}\rho^0$ & $K^{*0}\rho^0$ are too small !



Choose $K^{*0}\rho^-$ as an input, a fit to BR and f_L yields ρ_A=0.75, ϕ_A=-42°, slightly different from the ones ρ_A=0.60, ϕ_A=-50° inferred from $B\to K^*\phi$

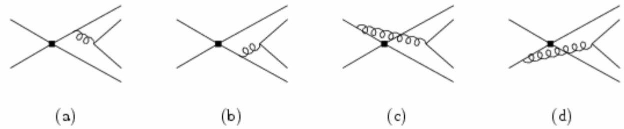
Decay	$\mathcal{B}$		f_L		$f_\perp$	
	Theory	Expt	Theory	Expt	Theory	Expt
$B^- \to \bar{K}^{*0}\rho^-$ [a]	$9.3^{+1.2+4.5}_{-1.1-5.6}$	9.2 ± 1.5	$0.50^{+0.50}_{-0.38}$	0.48 ± 0.08	$0.25^{+0.19}_{-0.25}$	
$B^- \to K^{*-}\rho^0$	$5.4^{+0.6+0.9}_{-0.5-2.4}$	< 6.1	$0.69^{+0.29}_{-0.47}$	$0.96^{+0.06}_{-0.16}$ [b]	$0.15^{+0.23}_{-0.14}$	
$\overline{B}^0 \to K^{*-}\rho^+$	$9.0^{+1.1+4.8}_{-1.0-5.5}$	< 12	$0.55^{+0.42}_{-0.31}$		$0.22^{+0.16}_{-0.21}$	
$\overline{B}^0 \to \bar{K}^{*0}\rho^0$	$4.7^{+0.6+4.0}_{-0.5-3.7}$	5.6 ± 1.6	$0.43^{+0.56}_{-0.29}$	0.57 ± 0.12	$0.29^{+0.15}_{-0.28}$	

$K^{*-}\rho^0$ was contaminated by $K^{*-}f_0(980)$ in previous 2003 measurement of $f_L(K^{*-}\rho^0)$. New BaBar measurement of f_L=0.9 ± 0.2 has only 2.5 significance

$$f_L(K^{*-}\rho^0) > f_L(K^{*-}\rho^+) > f_L(\bar{K}^{*0}\rho^-) > f_L(\bar{K}^{*0}\rho^0)$$

Comparison with Beneke, Rohrer, Yang

- sign difference in annihilation terms $A_3^{f,0}$ $A_3^{i,0}$



$$A_3^{f,0}(V_1 V_2) \approx -18\pi\alpha_s\left(r_\chi^{V_1} - r_\chi^{V_2}\right)(X_A^0 - 2)(2X_A^0 - 1),$$

$$A_3^{i,0}(V_1 V_2) \approx 18\pi\alpha_s\left(-r_\chi^{V_1} - r_\chi^{V_2}\right)\left(X_A^{0\,2} - 2X_A^0 + 4 - \frac{\pi^2}{3}\right) \qquad r_\chi^V(\mu) = \frac{2m_V}{m_b(\mu)}\frac{f_V^\perp(\mu)}{f_V}$$

BRY got a negative sign for r_χ^{v2}. Recall that annihilation in A_0 is governed by $A^{f,0}{}_3$ or $\beta_3{}^o$

- different c quark mass, $m_c(m_b)$=1.3±0.2 GeV (we use 0.91 GeV)

- BRY use the same ρ_A & ϕ_A parameters for B→$K^*\rho$ & $K^*\phi$

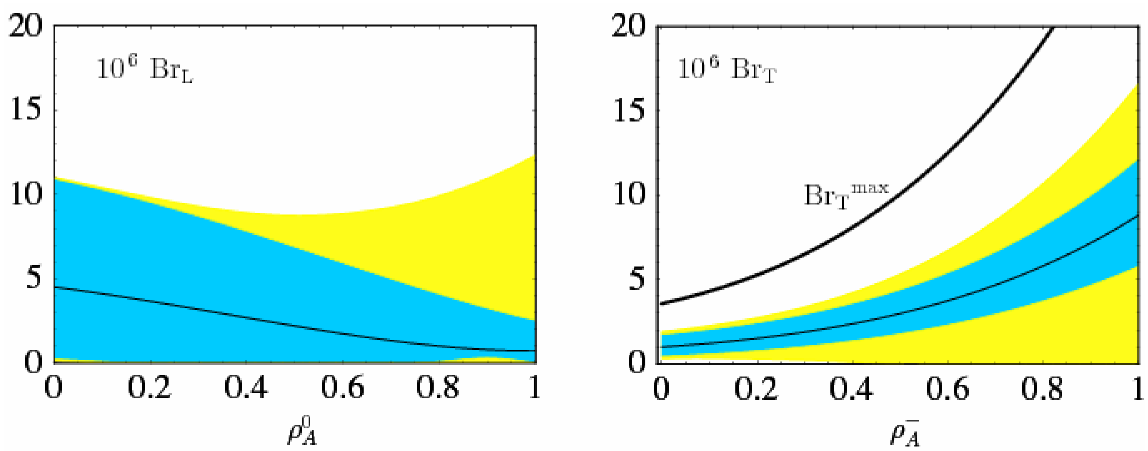
Decay	Expt $\mathcal{B}$	Expt f_L	BRY $\mathcal{B}$	BRY f_L	new f_L Beneke
$B^- \to \bar{K}^{*0}\rho^-$	9.2 ± 1.5	0.48 ± 0.08	$5.9^{+6.6}_{-3.7}$	$0.56^{+0.48}_{-0.30}$	$0.44^{+0.59}_{-0.40}$
$B^- \to K^{*-}\rho^0$	< 6.1	$0.96^{+0.06}_{-0.16}$	$4.5^{+3.4}_{-1.9}$	$0.84^{+0.16}_{-0.25}$	$0.61^{+0.44}_{-0.44}$
$\overline{B}^0 \to K^{*-}\rho^+$	< 12	–	$5.5^{+6.0}_{-3.3}$	$0.61^{+0.38}_{-0.29}$	$0.41^{+0.55}_{-0.20}$
$\overline{B}^0 \to \bar{K}^{*0}\rho^0$	5.6 ± 1.6	0.57 ± 0.12	$2.4^{+3.5}_{-2.0}$	$0.22^{+0.53}_{-0.14}$	$0.33^{+0.66}_{-0.18}$

<u>Kagan</u> ('04)

In absence of penguin ann, $f_L \approx 0.90$ (≈ 0.67 by BRY, ≈ 0.58 by us)

as Kagan didn't consider vertex and spectator corrections

Have to reply heavily on penguin ann to bring up f_T



In our case, we use penguin ann mainly to accommodate rate deficit rather than to enhance f_T

pQCD (Li, Mishima)

$Br(B \to K^* \phi) \sim 15 \times 10^{-6}$, $f_L \sim 0.75$ ($A_0 = 0.40$ for $B \to K^*$ transition)

$$
\begin{aligned}
A_L &\propto 2r_2\epsilon_2^*(L)\cdot\epsilon_3^*(L)A_0 \;, \\
A_{||} &\propto -\sqrt{2}(1+r_2)A_1 \;, \\
A_\perp &\propto -\frac{2r_2r_3}{1+r_2}\sqrt{2[(v_2\cdot v_3)^2-1]}V
\end{aligned}
$$

Li proposed to use $A_0 \sim 0.28$ to get

$Br(B \to K^* \phi) \sim 10 \times 10^{-6}$, $f_L \sim 0.59$

- too small A_0 ? (many people use $A_0 \sim 0.37$)
  not welcome for $B^0 \to K^{*0} \underline{K}^{*0}$ (see next)
- NLO corrections need to be considered (in progress)

Other VV modes

	Decay	$\mathcal{B}$ Theory	$\mathcal{B}$ Expt	f_L Theory	f_L Expt	$f_\perp$ Theory	$f_\perp$ Expt
tree	$B^- \to \rho^- \rho^0$	$20.1^{+4.0+2.0}_{-1.9-0.9}$	18.2 ± 3.0	$0.96^{+0.02}_{-0.02}$	$0.912^{+0.044}_{-0.045}$	0.02 ± 0.01	
	$\overline{B}^0 \to \rho^+ \rho^-$	$25.3^{+1.5+2.4}_{-2.6-1.5}$	$24.2^{+3.1}_{-3.2}$	$0.92^{+0.01}_{-0.02}$	$0.978^{+0.025}_{-0.022}$	$0.04^{+0.01}_{-0.00}$	
	$\overline{B}^0 \to \rho^0 \rho^0$	$0.9^{+1.5+1.1}_{-0.4-0.2}$	0.68 ± 0.27	$0.92^{+0.06}_{-0.36}$	0.70 ± 0.15	$0.04^{+0.14}_{-0.03}$	
	$B^- \to \rho^- \omega$	$19.1^{+3.3+1.7}_{-1.6-1.0}$	$10.6^{+2.6}_{-2.3}$	$0.96^{+0.02}_{-0.02}$	0.82 ± 0.11	0.02 ± 0.01	
	$\overline{B}^0 \to \rho^0 \omega$	$0.1^{+0.1+0.4}_{-0.1-0.0}$	< 1.5	$0.55^{+0.47}_{-0.29}$		$0.22^{+0.16}_{-0.23}$	
penguin	$B^- \to K^{*-} \omega$	$3.5^{+0.4+3.5}_{-0.4-1.8}$	< 3.4	$0.67^{+0.32}_{-0.36}$		$0.16^{+0.18}_{-0.16}$	
	$\overline{B}^0 \to \bar{K}^{*0} \omega$	$3.0^{+0.5+3.4}_{-0.4-1.8}$	< 2.7	$0.57^{+0.44}_{-0.41}$		0.21 ± 0.22	
	$B^- \to K^{*0} K^{*-}$	$0.6^{+0.1+0.3}_{-0.1-0.3}$	< 71	$0.48^{+0.51}_{-0.38}$		$0.26^{+0.19}_{-0.26}$	
	$\overline{B}^0 \to K^{*-} K^{*+}$	$0.1^{+0.0+0.1}_{-0.0-0.1}$	< 141	1		0	
	$\overline{B}^0 \to K^{*0} \bar{K}^{*0}$	$0.6^{+0.1+0.2}_{-0.1-0.3}$	$1.28^{+0.37}_{-0.32}$	$0.52^{+0.48}_{-0.47}$	$0.80^{+0.12}_{-0.13}$	$0.24^{+0.23}_{-0.24}$	

- Longitudinal amplitude dominates tree-dominated decays except for $\rho^0\omega$
- B→ ω form factors are slightly smaller than what expected from light-cone sum rules

B→VA ($A=a_1, b_1, K_1, f_1, h_1$)

	Mode	Br	f_L	Mode	Br	f_L
tree	$\overline{B}^0 \to a_1^+ \rho^-$	$23.8^{+10.5+3.2}_{-9.2-0.4}$	$(0.82^{+0.05}_{-0.13})$	$\overline{B}^0 \to b_1^+ \rho^-$	$32.1^{+16.5+12.0}_{-14.7-4.7}$	$(0.96^{+0.01}_{-0.02})$
	$\overline{B}^0 \to a_1^- \rho^+$	$35.8^{+3.4+2.6}_{-3.8-0.4}$	$(0.84^{+0.02}_{-0.06})$	$\overline{B}^0 \to b_1^- \rho^+$	$0.6^{+0.6+1.8}_{-0.3-0.2}$	$(0.98^{+0.00}_{-0.32})$
	$\overline{B}^0 \to a_1^0 \rho^0$	$1.2^{+2.0+5.2}_{-0.6-0.2}$	$(0.83^{+0.06}_{-0.88})$	$\overline{B}^0 \to b_1^0 \rho^0$	$0.4^{+0.4+21.3}_{-0.2-0}$	$(0.82^{+0.16}_{-0.51})$
	$B^- \to a_1^0 \rho^-$	$17.9^{+10.2+1.0}_{-6.4-0.2}$	$(0.91^{+0.05}_{-0.03})$	$B^- \to b_1^0 \rho^-$	$29.0^{+16.2+5.4}_{-10.6-5.8}$	$(0.96^{+0.01}_{-0.06})$
	$B^- \to a_1^- \rho^0$	$23.1^{+3.6+4.0}_{-2.9-0.1}$	$(0.89^{+0.11}_{-0.16})$	$B^- \to b_1^- \rho^0$	$0.9^{+1.7+2.6}_{-0.6-0.5}$	$(0.90^{+0.06}_{-0.33})$
	$\overline{B}^0 \to a_1^0 \omega$	$0.2^{+0.1+0.8}_{-0.1-0}$	$(0.82^{+0.05}_{-0.89})$	$\overline{B}^0 \to b_1^0 \omega$	$0.1^{+0.2+1.4}_{-0.0-0.0}$	$(0.10^{+1.04}_{-0.01})$
	$B^- \to a_1^- \omega$	$22.4^{+3.3+3.2}_{-2.7-0.4}$	$(0.88^{+0.10}_{-0.15})$	$B^- \to b_1^- \omega$	$0.9^{+1.4+2.7}_{-0.5-0.3}$	$(0.91^{+0.07}_{-0.33})$
penguin	$\overline{B}^0 \to a_1^0 \phi$	$0.002^{+0.016+0.043}_{-0.007-0.009}$	$(0.94^{+0.01}_{-0.69})$	$\overline{B}^0 \to b_1^0 \phi$	$0.01^{+0.01+0.01}_{-0.00-0.00}$	$(0.98^{+0.01}_{-0.33})$
	$B^- \to a_1^- \phi$	$0.01^{+0.01+0.04}_{-0.00-0.00}$	$(0.94^{+0.01}_{-0.69})$	$B^- \to b_1^- \phi$	$0.02^{+0.02+0.03}_{-0.01-0.00}$	$(0.98^{+0.01}_{-0.33})$
	$\overline{B}^0 \to a_1^+ K^{*-}$	$7.0^{+4.5+25.2}_{-3.0-7.1}$	$(0.19^{+0.09}_{-0.15})$	$\overline{B}^0 \to b_1^+ K^{*-}$	$7.6^{+3.3+40.7}_{-2.4-7.1}$	$(0.71^{+0.17}_{-0.66})$
	$\overline{B}^0 \to a_1^0 \overline{K}^{*0}$	$1.7^{+1.1+8.6}_{-0.7-1.6}$	$(0.20^{+0.51}_{-0.14})$	$\overline{B}^0 \to b_1^0 \overline{K}^{*0}$	$3.0^{+1.1+4.6}_{-0.7-2.1}$	$(0.80^{+0.20}_{-0.70})$
	$B^- \to a_1^- \overline{K}^{*0}$	$9.7^{+4.9+32.9}_{-3.5-2.4}$	$(0.38^{+0.51}_{-0.40})$	$B^- \to b_1^- \overline{K}^{*0}$	$12.1^{+4.4+21.2}_{-3.2-2.7}$	$(0.80^{+0.20}_{-0.70})$
	$B^- \to a_1^0 K^{*-}$	$7.1^{+2.6+16.8}_{-2.0-3.4}$	$(0.55^{+0.40}_{-0.46})$	$B^- \to b_1^0 K^{*-}$	$6.8^{+2.4+12.5}_{-1.8-4.4}$	$(0.84^{+0.15}_{-0.29})$

- $\Gamma(B^0 \to b_1^+ \rho^-) \gg \Gamma(B^0 \to b_1^- \rho^+)$
- BaBar: $Br(B^0 \to a_1^\pm \rho^\mp) < 61\times10^{-6}$; $Br(B^0 \to b_1^\pm \rho^\mp) < 1.7\times10^{-6}$ (FPCP2008)

  Naively, it is expected that $b_1^+\rho^- \sim 3\, b_1^+\pi^- \sim 30\times10^{-6}$
- a_1K^* modes are dominated by transverse amplitudes

$B \to AA$

Decay	$\theta_{K_1}=-37^\circ$		$\theta_{K_1}=-58^\circ$	
	$\mathcal{B}$	f_L	$\mathcal{B}$	f_L
$\overline{B}^0 \to K_1^-(1270)a_1^+$	$32.0^{+43.2+174.8}_{-20.5-30.5}$	$0.21^{+0.18}_{-0.07}$	$36.4^{+46.8+184.0}_{-23.2-33.5}$	$0.14^{+0.31}_{-0.06}$
$\overline{B}^0 \to \bar{K}_1^0(1270)a_1^0$	$16.0^{+22.0+85.9}_{-10.4-15.5}$	$0.21^{+0.71}_{-0.13}$	$17.4^{+23.7+92.4}_{-11.7-17.0}$	$0.11^{+0.27}_{-0.03}$
$B^- \to \bar{K}_1^0(1270)a_1^-$	$33.4^{+45.1+175.8}_{-21.5-32.2}$	$0.19^{+0.22}_{-0.16}$	$38.1^{+48.5+183.5}_{-24.1-36.0}$	$0.13^{+0.31}_{-0.13}$
$B^- \to K_1^-(1270)a_1^0$	$18.8^{+22.4+89.6}_{-10.8-1.9}$	$0.26^{+0.41}_{-0.15}$	$21.4^{+24.2+91.3}_{-12.1-17.7}$	$0.21^{+0.44}_{-0.13}$
$\overline{B}^0 \to K_1^-(1400)a_1^+$	$10.1^{+8.7+12.8}_{-4.8-6.7}$	$0.31^{+0.33}_{-0.27}$	$5.0^{+4.5+20.6}_{-1.8-3.9}$	$0.92^{+0.04}_{-0.53}$
$\overline{B}^0 \to \bar{K}_1^0(1400)a_1^0$	$5.5^{+4.4+7.7}_{-2.5-3.7}$	$0.39^{+0.51}_{-0.37}$	$3.8^{+2.7+11.9}_{-1.4-2.9}$	$0.96^{+0.15}_{-0.44}$
$B^- \to \bar{K}_1^0(1400)a_1^-$	$11.4^{+9.2+17.7}_{-5.2-8.5}$	$0.37^{+0.63}_{-0.37}$	$5.9^{+5.1+22.3}_{-2.2-5.0}$	$0.95^{+0.08}_{-0.54}$
$B^- \to K_1^-(1400)a_1^0$	$5.1^{+4.3+7.3}_{-2.3-0.9}$	$0.28^{+0.35}_{-0.24}$	$2.1^{+2.2+9.5}_{-0.8-1.6}$	$0.88^{+0.08}_{-0.72}$
$\overline{B}^0 \to K_1^-(1270)b_1^+$	$12.9^{+9.7+66.5}_{-5.8-11.5}$	$0.37^{+0.47}_{-0.18}$	$11.8^{+10.7+67.2}_{-4.8-8.3}$	$0.20^{+0.65}_{-0.24}$
$\overline{B}^0 \to \bar{K}_1^0(1270)b_1^0$	$6.5^{+4.8+33.4}_{-2.8-5.7}$	$0.37^{+0.46}_{-0.30}$	$6.0^{+5.1+36.0}_{-2.2-3.9}$	$0.20^{+0.65}_{-0.25}$
$B^- \to \bar{K}_1^0(1270)b_1^-$	$13.5^{+10.4+73.2}_{-6.0-12.7}$	$0.39^{+0.39}_{-0.27}$	$11.1^{+10.2+73.5}_{-4.2-8.2}$	$0.13^{+0.62}_{-0.12}$
$B^- \to K_1^-(1270)b_1^0$	$7.9^{+6.5+36.6}_{-3.7-0.9}$	$0.47^{+0.41}_{-0.25}$	$6.9^{+6.5+34.3}_{-2.9-4.4}$	$0.30^{+0.57}_{-0.30}$
$\overline{B}^0 \to K_1^-(1400)b_1^+$	$20.2^{+21.4+199.7}_{-8.8-18.1}$	$0.91^{+0.03}_{-0.31}$	$21.7^{+20.3+199.7}_{-10.1-19.7}$	$0.98^{+0.02}_{-0.37}$
$\overline{B}^0 \to \bar{K}_1^0(1400)b_1^0$	$10.8^{+10.6+106.9}_{-4.5-10.2}$	$0.90^{+0.06}_{-0.80}$	$11.5^{+10.4+104.5}_{-5.3-10.8}$	$0.98^{+0.02}_{-0.71}$
$B^- \to \bar{K}_1^0(1400)b_1^-$	$22.9^{+22.8+224.5}_{-9.7-21.7}$	$0.90^{+0.05}_{-0.82}$	$25.7^{+23.3+225.0}_{-12.0-24.5}$	$0.98^{+0.02}_{-0.84}$
$B^- \to K_1^-(1400)b_1^0$	$10.7^{+11.4+104.8}_{-4.7-0.2}$	$0.91^{+0.01}_{-0.33}$	$12.0^{+11.3+107.6}_{-5.7-11.2}$	$0.98^{+0.02}_{-0.50}$

Penguin-dominated K_1A modes (except for K_1b_1) have sizable transverse polarization; see arXiv:0805.0329 for details

Conclusions

- **NLO corrections to a_i^h can render A^- comparable to A^0 in some VV modes and hence will bring up transverse polarization; no indication for new physics.**
- **Decay rates should be produced correctly before making a sensible prediction for polarization fractions**
- **Rate deficit puzzle is more serious than polarization one**